An example of a large-scale interdisciplinary carbon problem

- Multidecadal climate variability
- Atmospheric evidence
- Ocean source? (upwelling, biological pump)
- Terrestrial source? (fire, enhanced storage)
- Anthropogenic? (fossil fuel consumption)

REVIEW

CLIMATE

From Anchovies to Sardines and Back: Multidecadal Change in the Pacific Ocean

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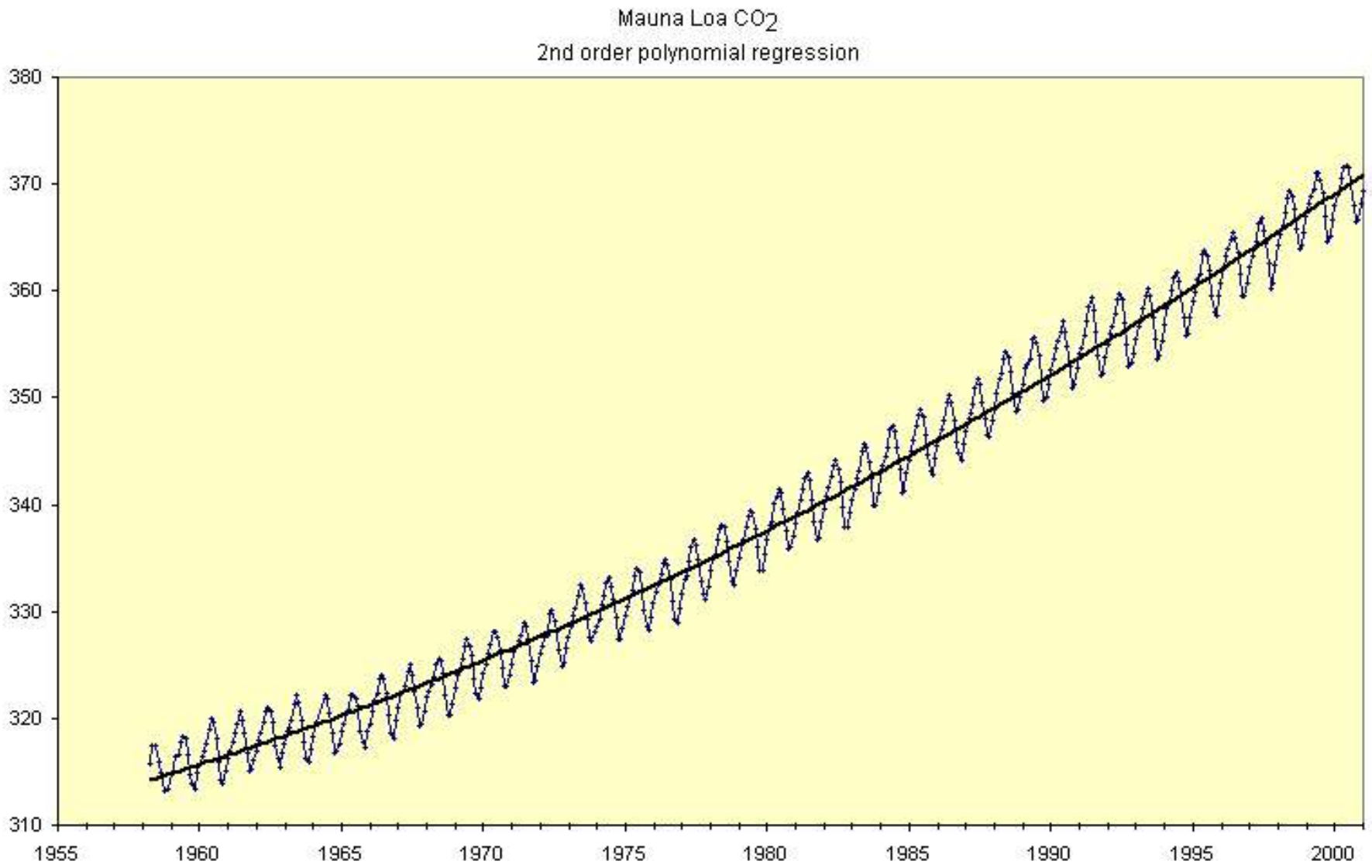
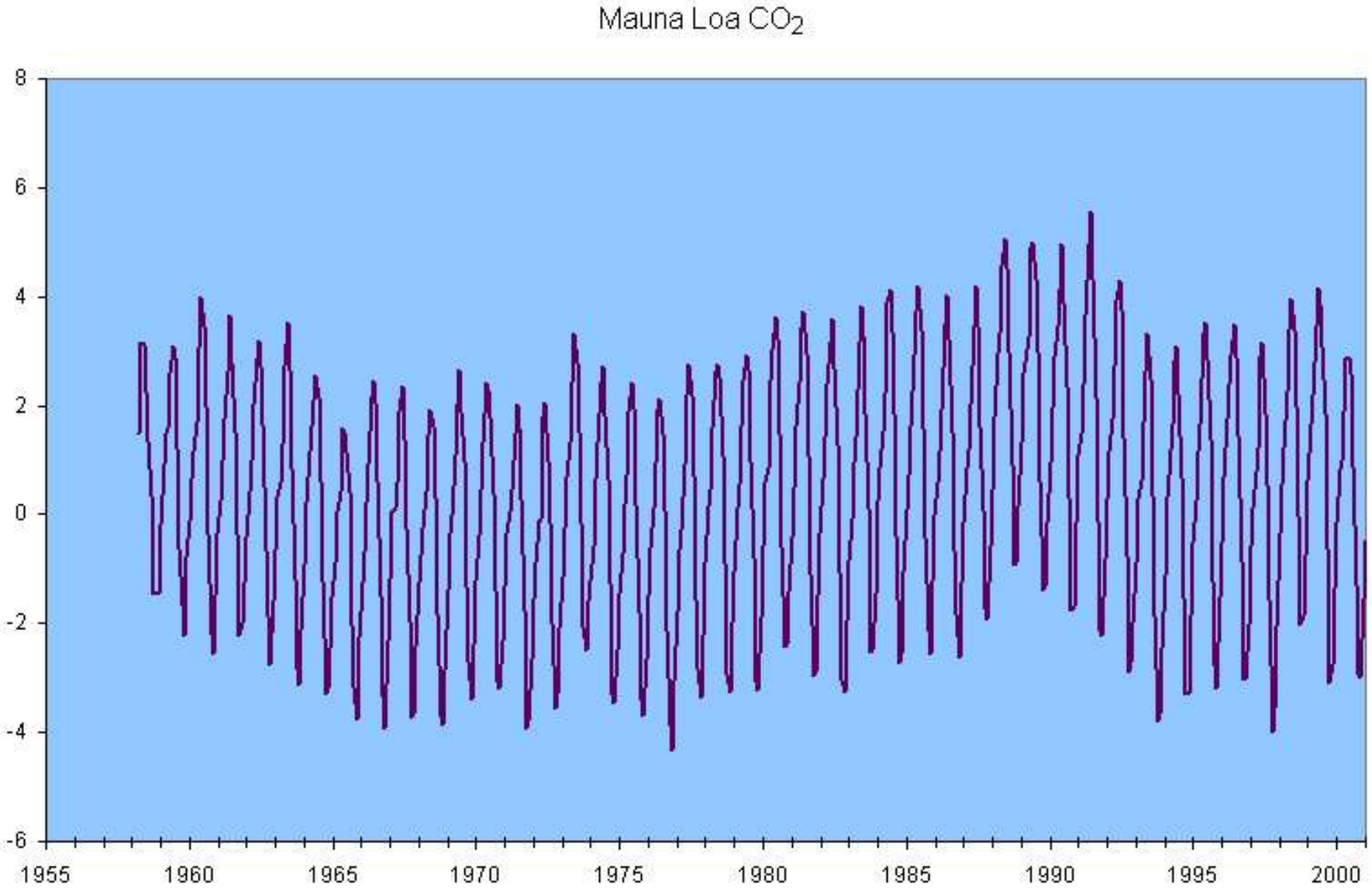
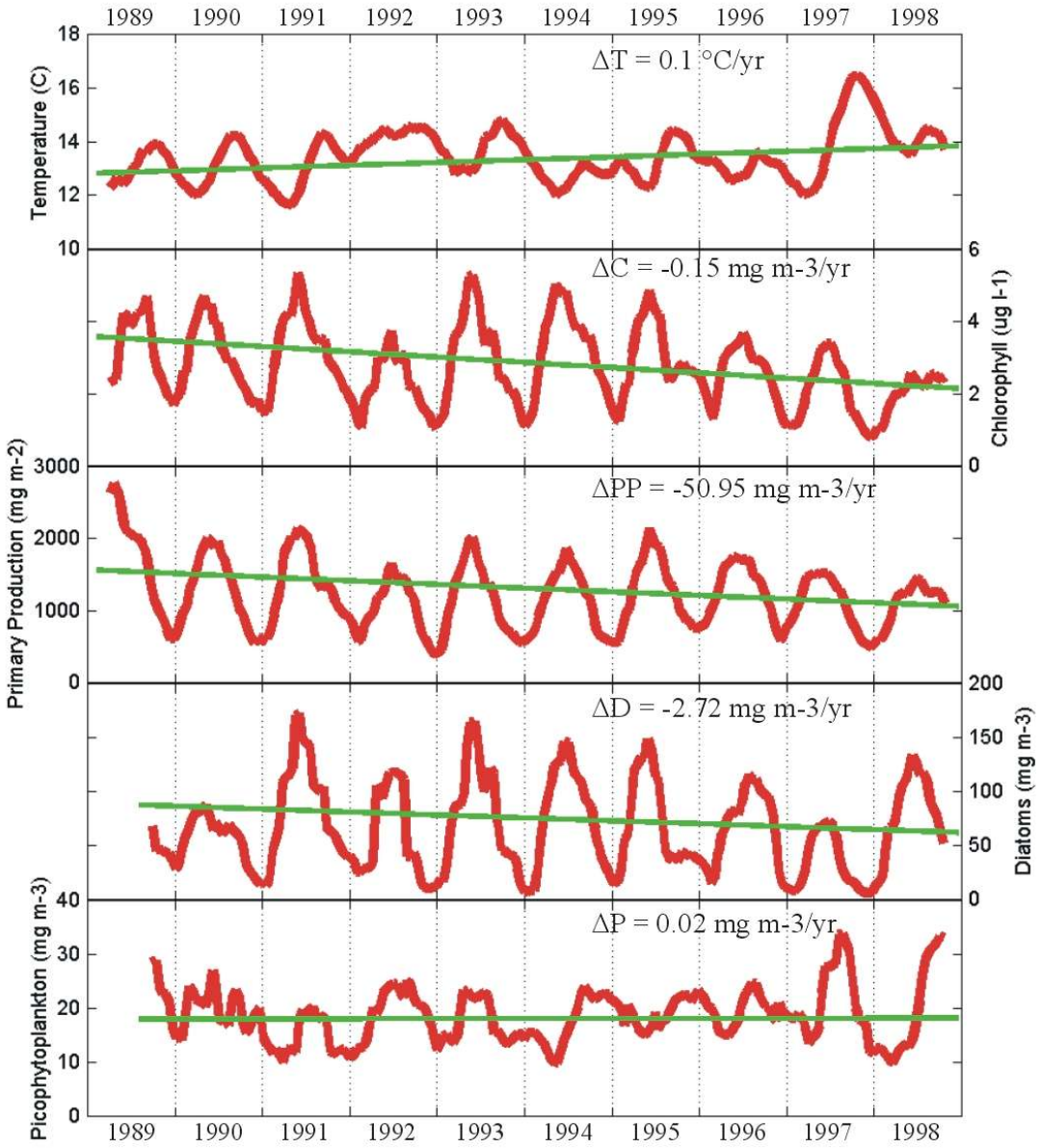
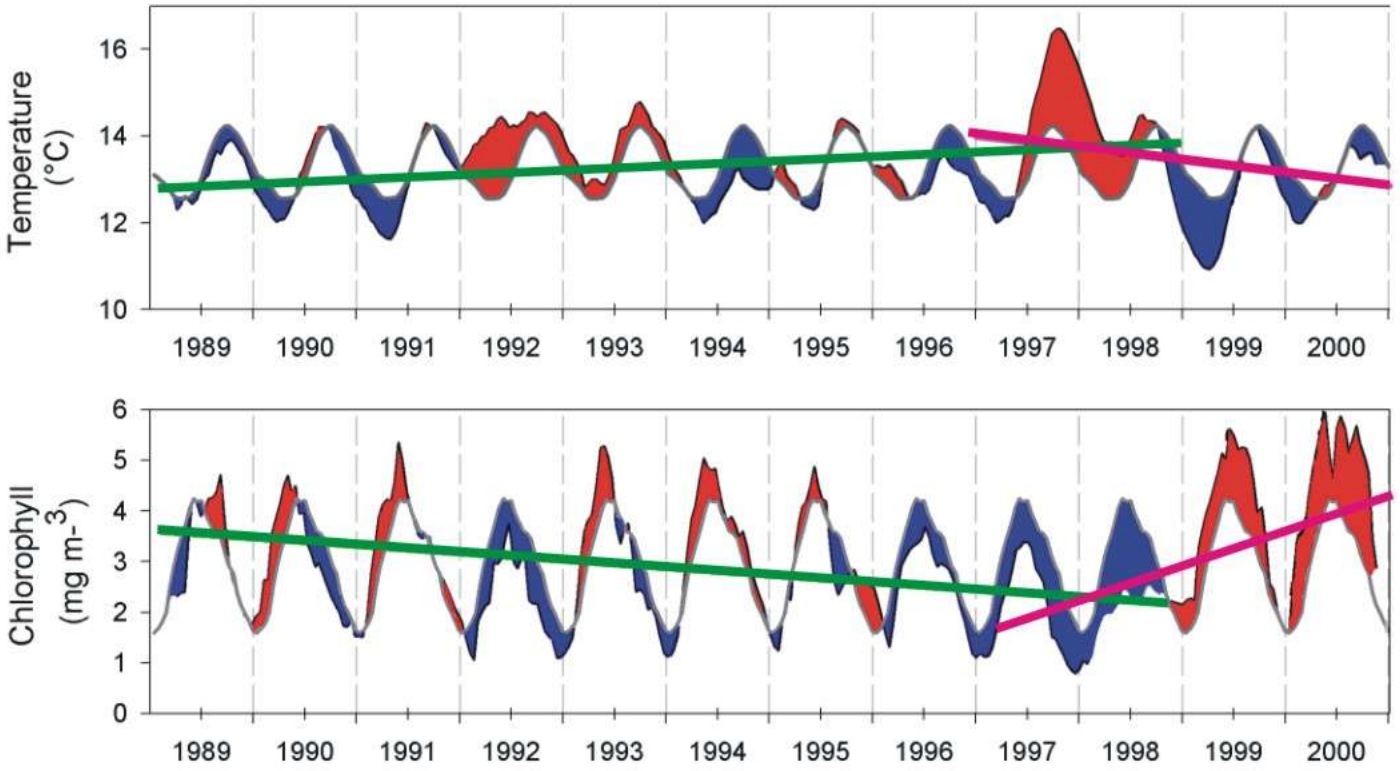
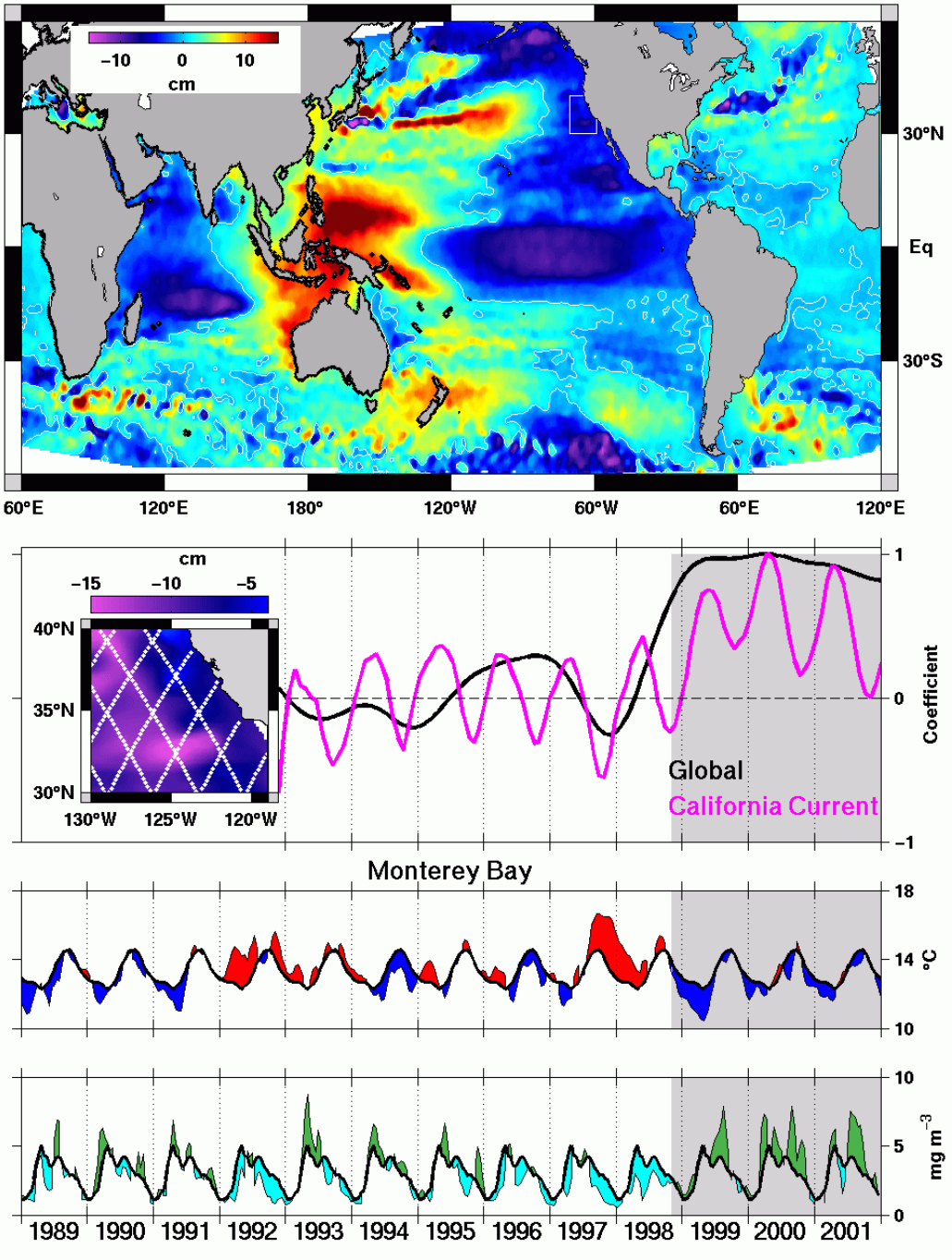

Mauna Loa CO_2
2nd order polynomial regression
380
370
360
350
340
330
320
310
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000


Mauna Loa CO_2
8
6
4
2
0
-2
-4
-6
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000


1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
ΔT = 0.1 °C/yr
Temperature (C)
ΔC = -0.15 mg m-3/yr
Chlorophyll (ug l-1)
ΔPP = -50.95 mg m-3/yr
Primary Production (mg m-2)
ΔD = -2.72 mg m-3/yr
Diatoms (mg m-3)
ΔP = 0.02 mg m-3/yr
Picophytoplankton (mg m-3)


Temperature (°C)
16
14
12
10
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Chlorophyll (mg m-3)
6
5
4
3
2
1
0
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000


−10
0
10
cm
30°N
Eq
30°S
60°E
120°E
180°
120°W
60°W
60°E
120°E
cm
−15
−10
−5
40°N
35°N
30°N
130°W
125°W
120°W
1
0
−1
Coefficient
Global
California Current
Monterey Bay
18
14
°C
10
10
5
0
mg m^{-3}
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

Sardine Landings

Japan

California

Peru

South Africa

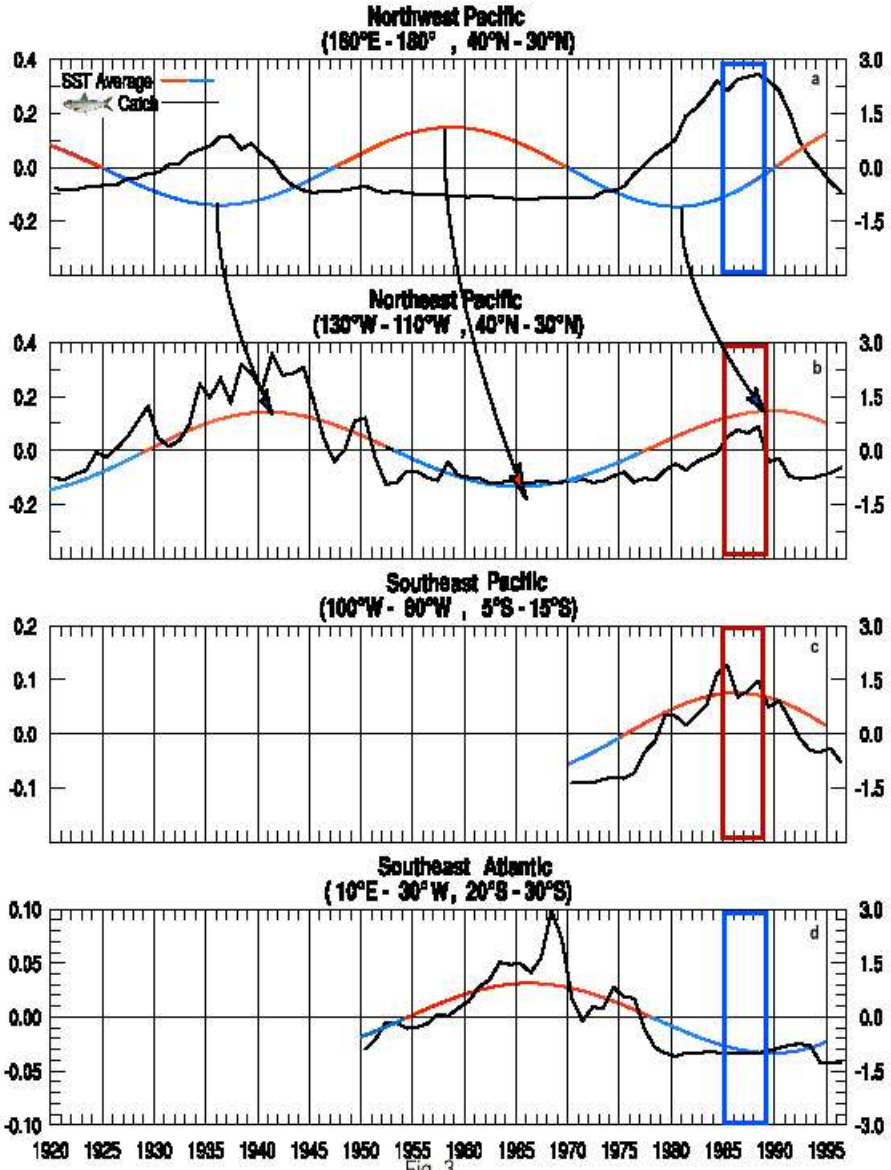
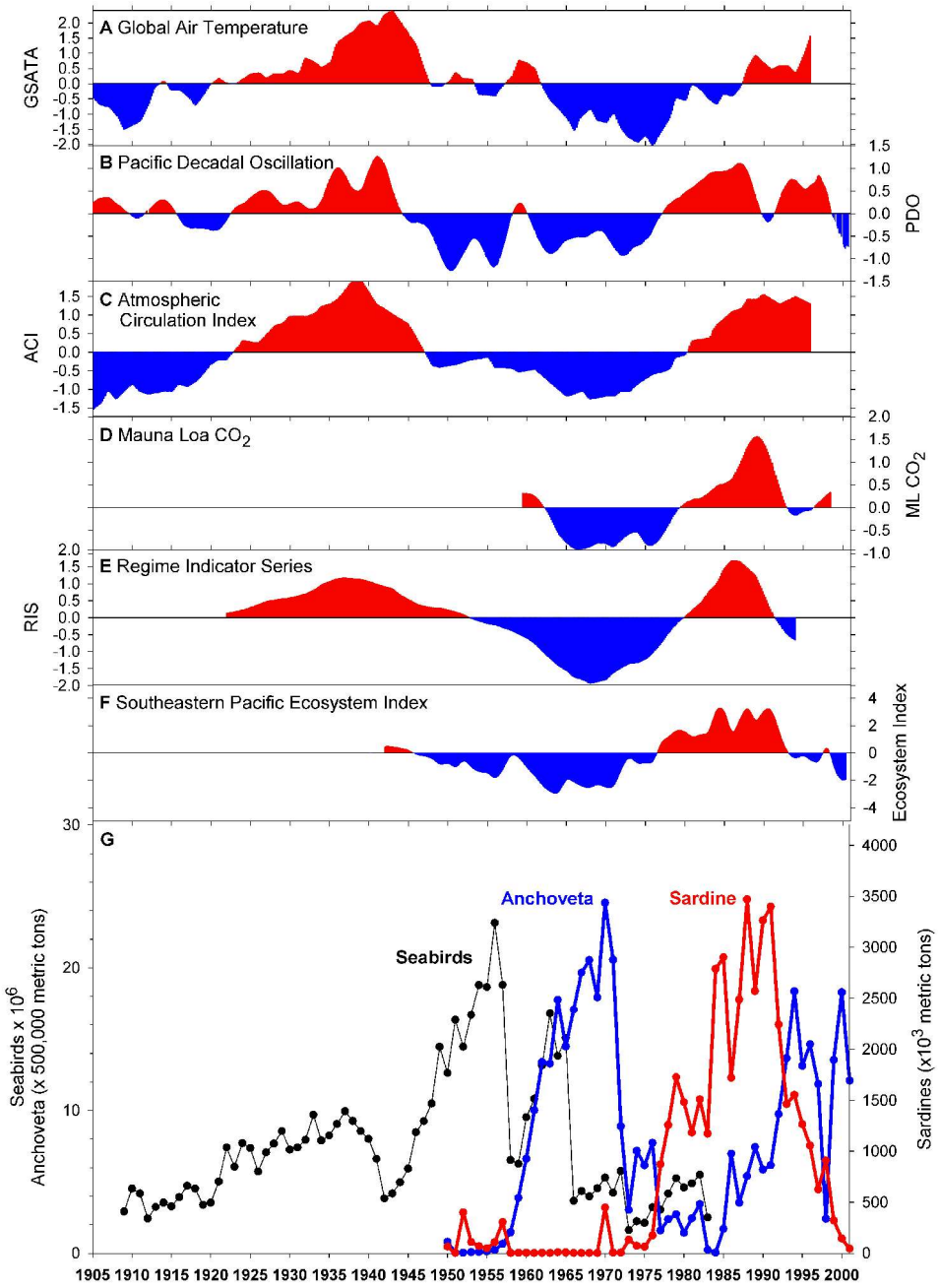
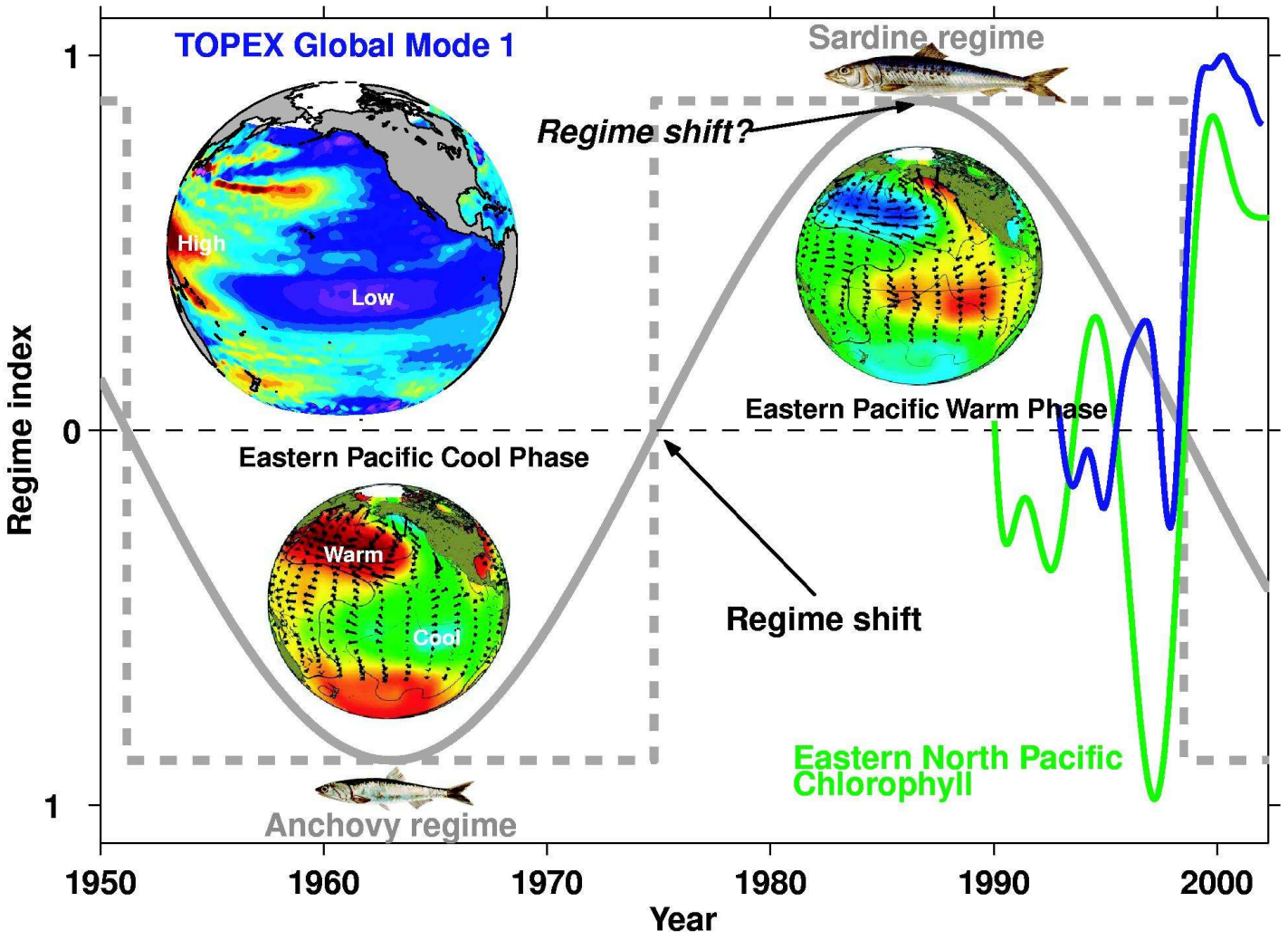
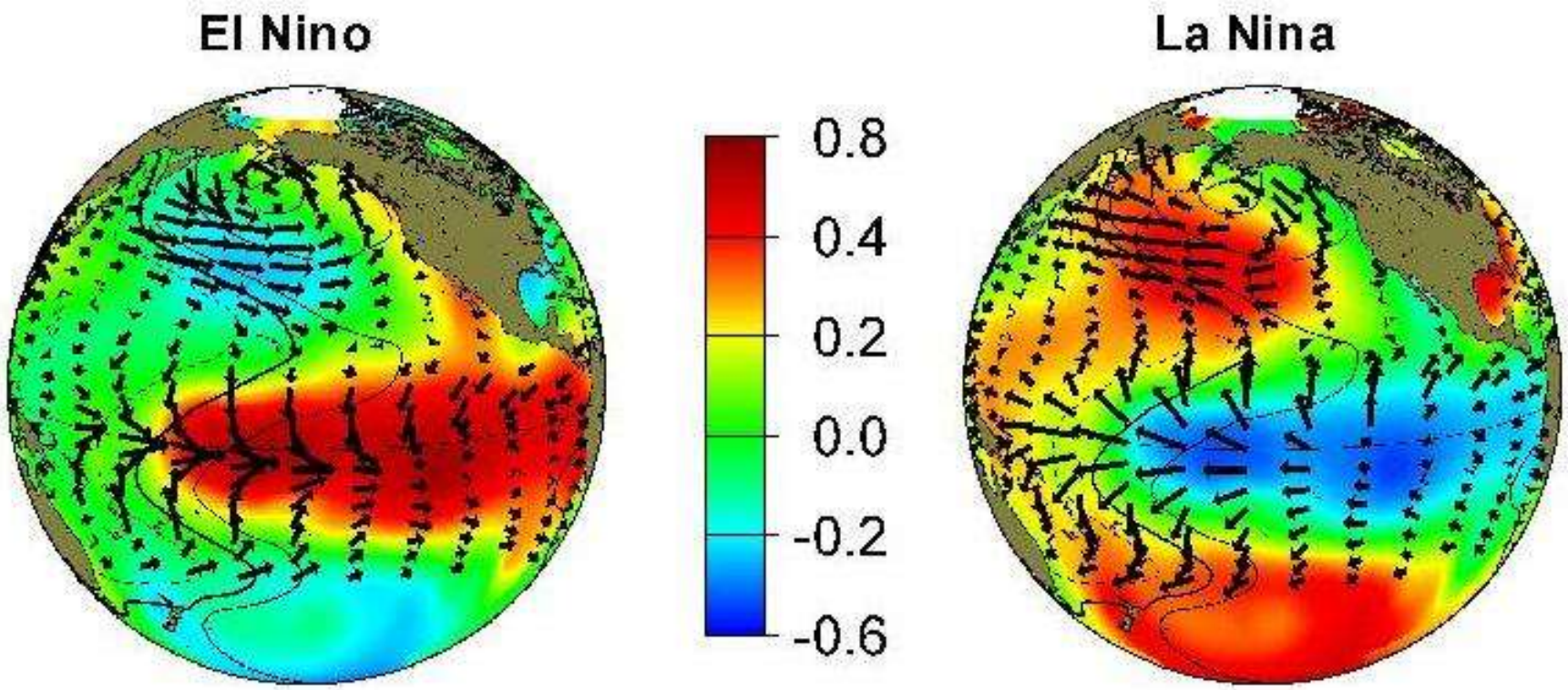


Fig. 3


A Global Air Temperature
GSATA
B Pacific Decadal Oscillation
PDO
C Atmospheric Circulation Index
ACI
D Mauna Loa CO_2
ML CO_2
E Regime Indicator Series
RIS
F Southeastern Pacific Ecosystem Index
Ecosystem Index
G
Anchoveta
Sardine
Seabirds
Seabirds x 10^6
Anchoveta (x 500,000 metric tons)
Sardines (x10^3 metric tons)
1905 1910 1915 1920 1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000

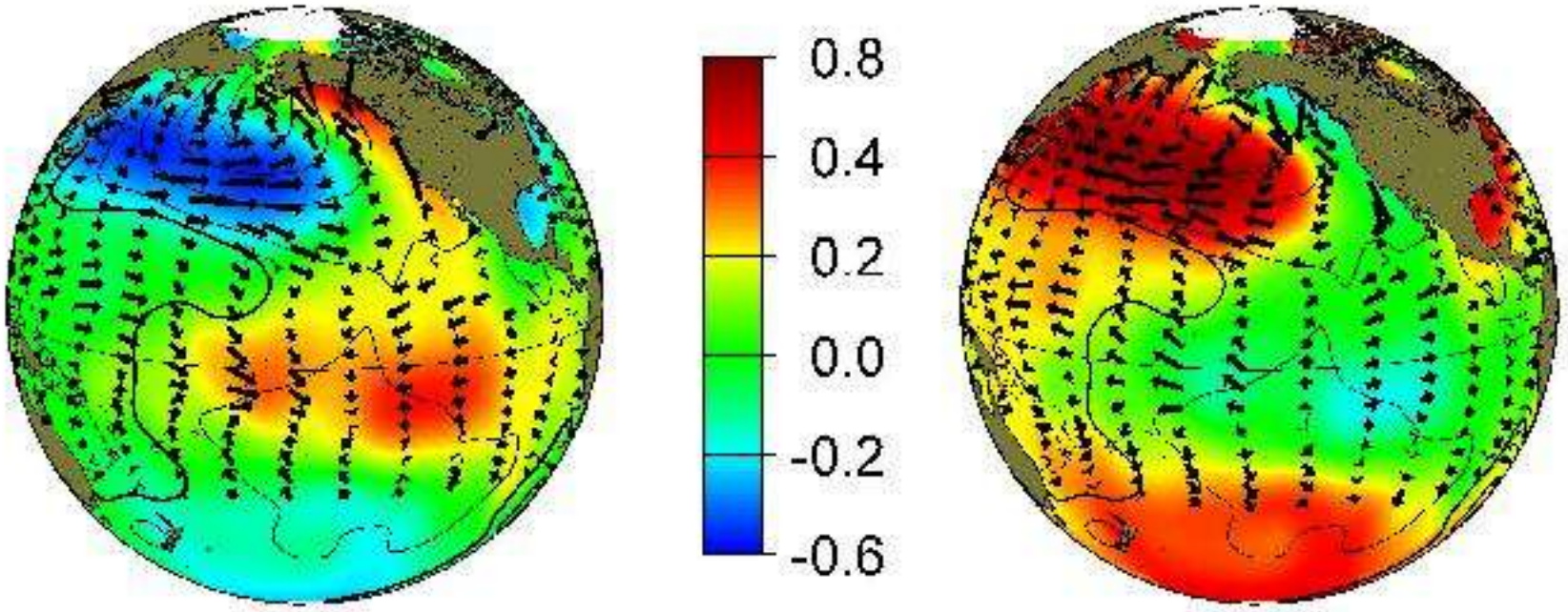

TOPEX Global Mode 1
Sardine regime
Regime shift?
High
Low
Eastern Pacific Warm Phase
Eastern Pacific Cool Phase
Warm
Cool
Regime shift
Eastern North Pacific
Chlorophyll
Anchovy regime
Regime index
1
0
1
1950
1960
1970
1980
1990
2000
Year

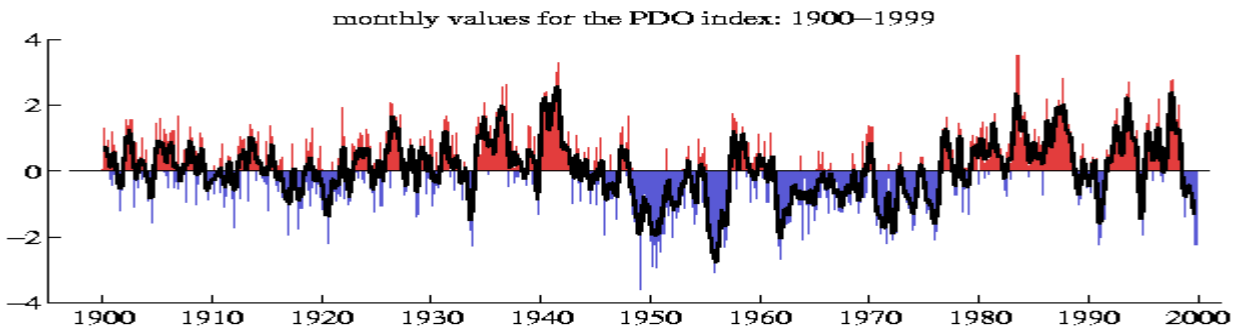
El Nino Southern Oscillation

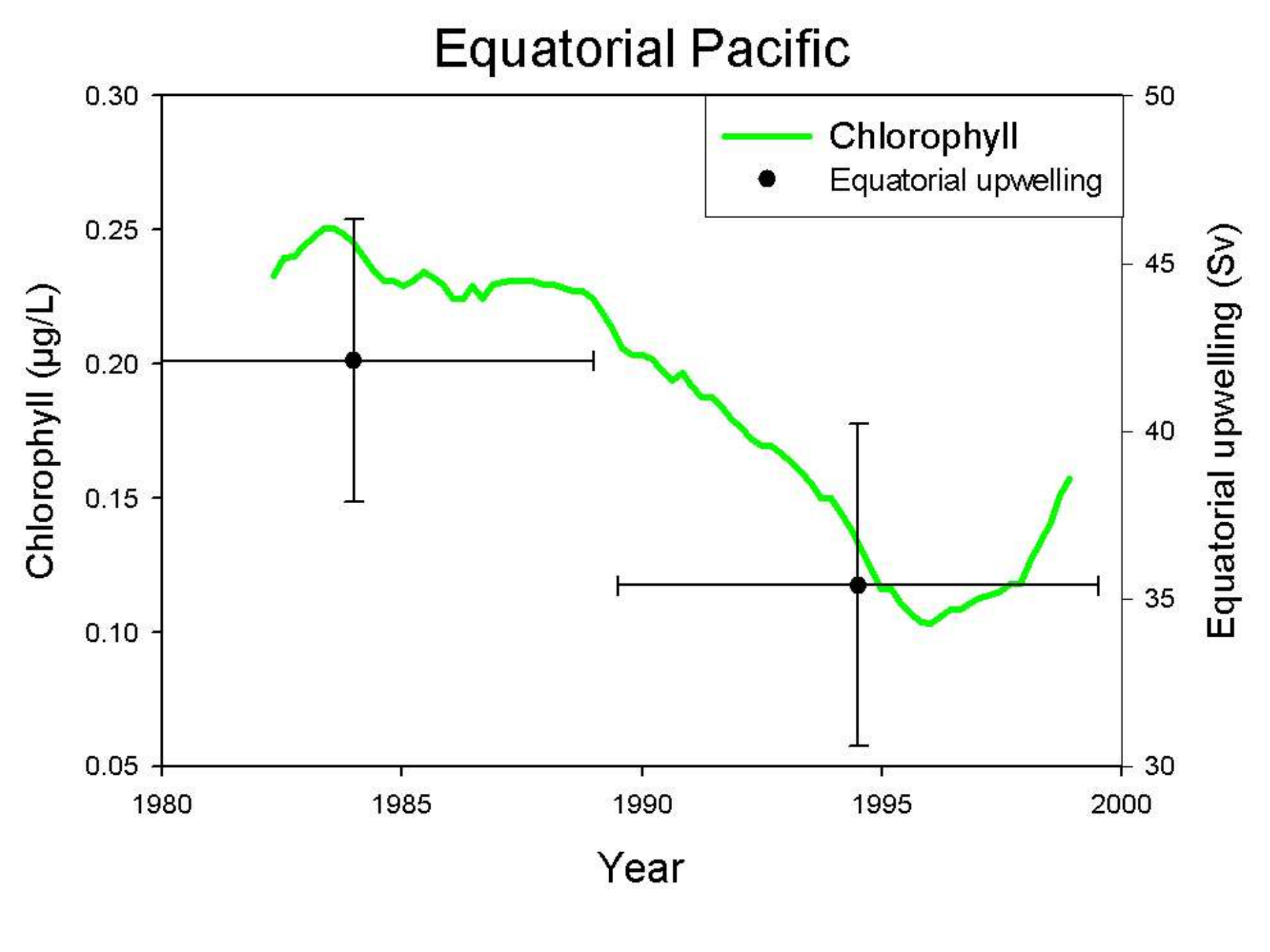


El Viejo

La Vieja






Equatorial Pacific
Chlorophyll
Equatorial upwelling
Chlorophyll (µg/L)
Equatorial upwelling (Sv)
Year
0.30
0.25
0.20
0.15
0.10
0.05
50
45
40
35
30
1980
1985
1990
1995
2000

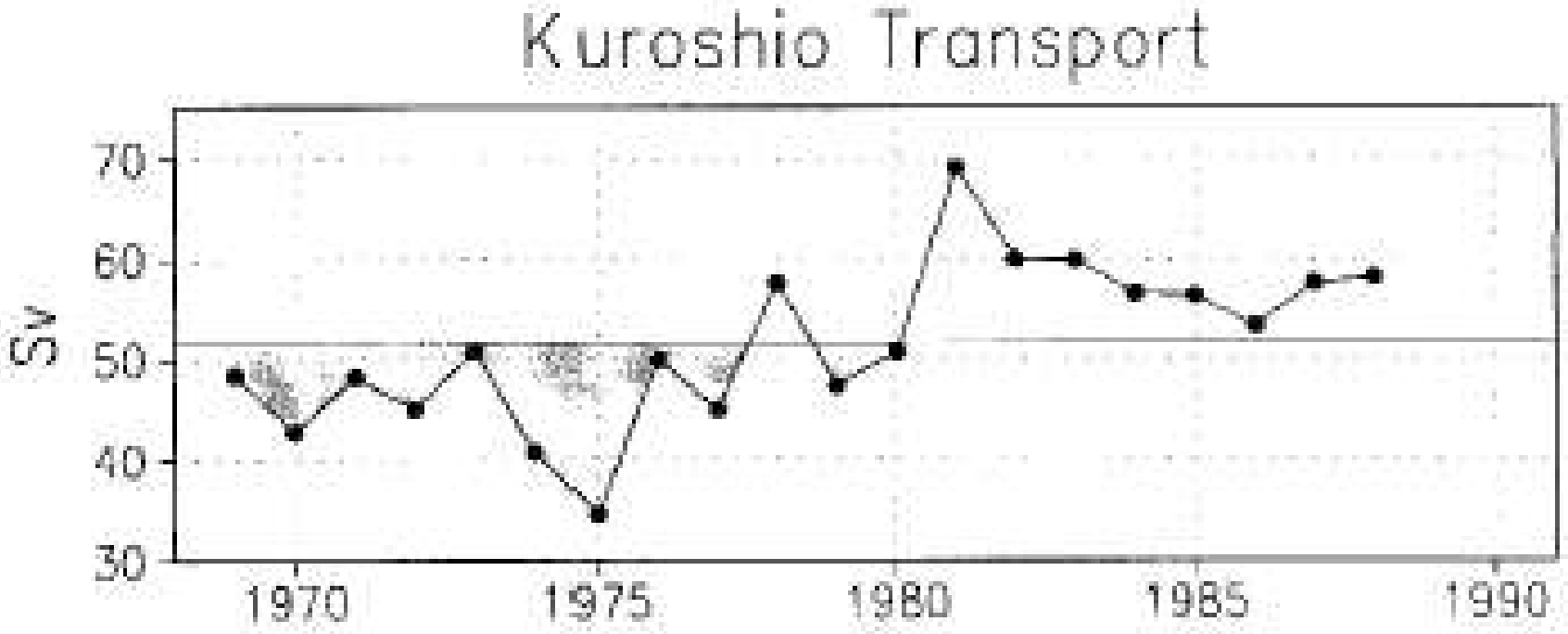
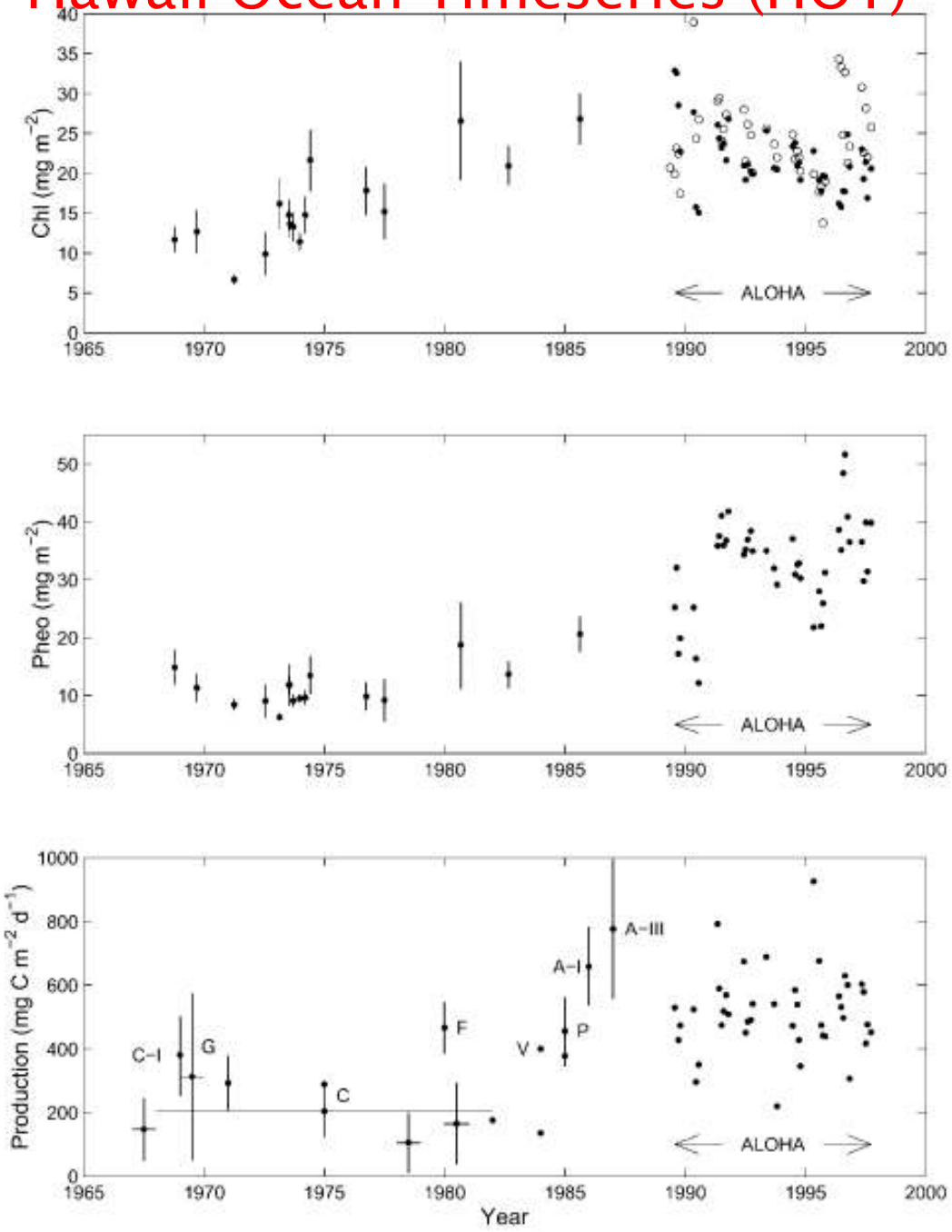
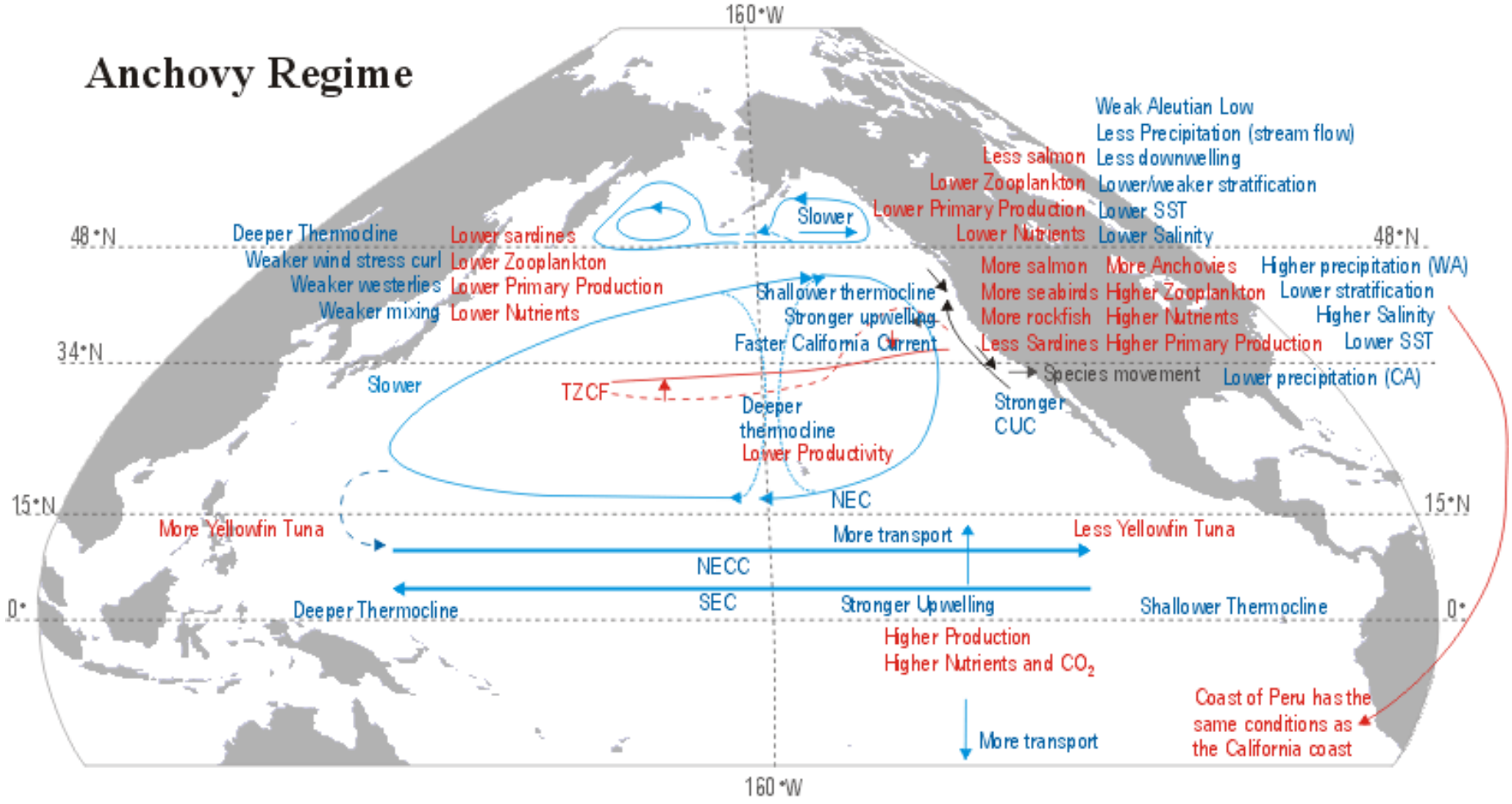


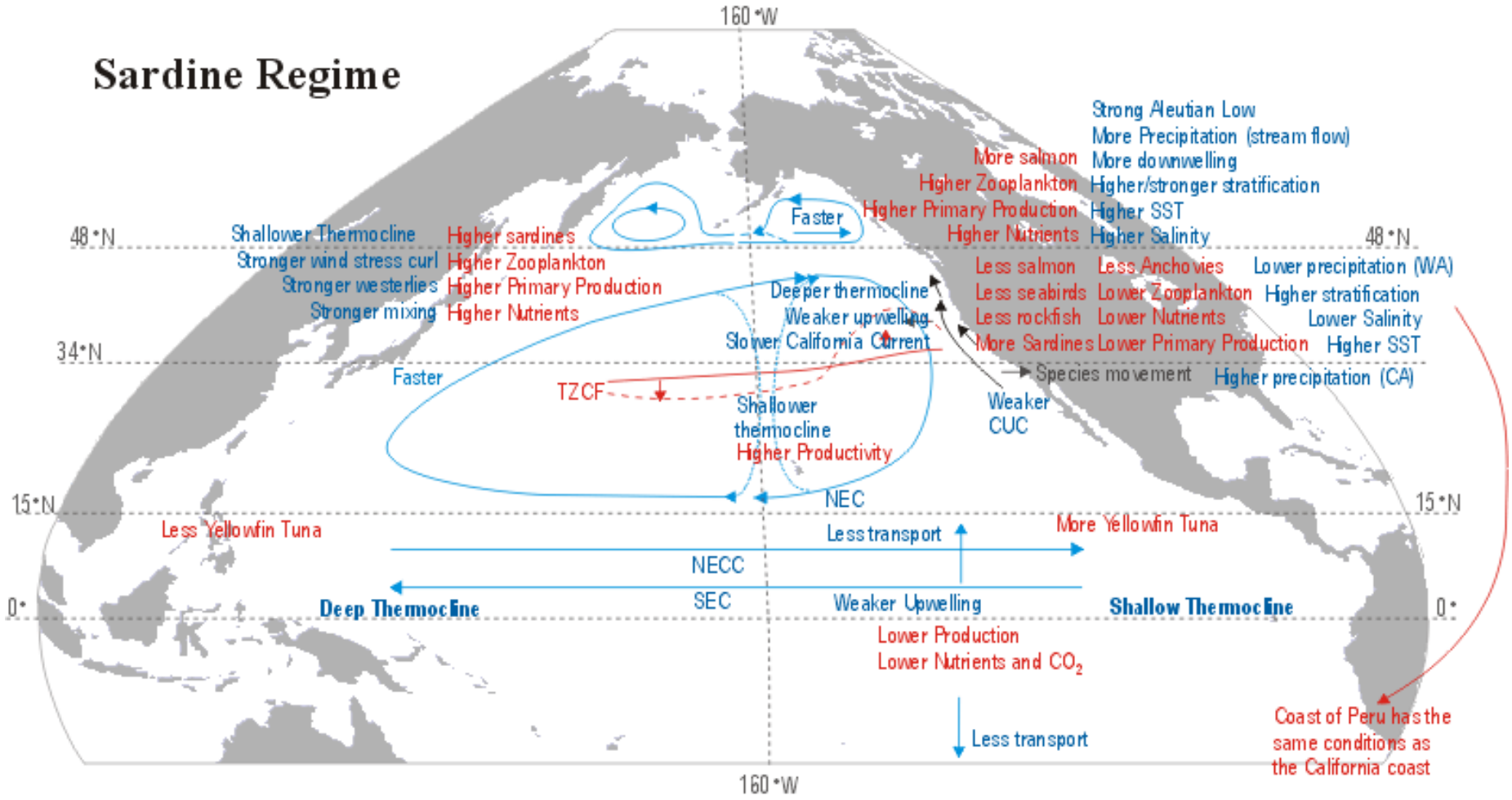
FIG. 9. Time series of geostrophic eastward transport Sverdrups (Sv) of the Kuroshio Current south of Japan referenced to 1.25 km, taken from Qiu and Joyce (1992). The thin horizontal line denotes the mean transport during 1969–88 (51.7 Sv).

Hawaii Ocean Timeseries (HOT)




Anchovy Regime
160°W
48°N
34°N
15°N
0°
Weak Aleutian Low
Less Precipitation (stream flow)
Less salmon
Less downwelling
Lower Zooplankton
Lower/weaker stratification
Lower Primary Production
Lower SST
Lower Nutrients
Lower Salinity
Deeper Thermocline
Lower sardines
Weaker wind stress curl
Lower Zooplankton
Weaker westerlies
Lower Primary Production
Weaker mixing
Lower Nutrients
Slower
Shallower thermocline
Stronger upwelling
Faster California Current
More salmon
More Anchovies
Higher precipitation (WA)
More seabirds
Higher Zooplankton
Lower stratification
More rockfish
Higher Nutrients
Higher Salinity
Less Sardines
Higher Primary Production
Lower SST
Species movement
Lower precipitation (CA)
Slower
TZCF
Deeper thermocline
Lower Productivity
Stronger CUC
NEC
More Yellowfin Tuna
More transport
Less Yellowfin Tuna
NECC
SEC
Deeper Thermocline
Stronger Upwelling
Shallower Thermocline
Higher Production
Higher Nutrients and CO_2
More transport
Coast of Peru has the same conditions as the California coast
160°W

La Vieja


Sardine Regime
160 °W
48 °N
34 °N
15 °N
0°
Strong Aleutian Low
More Precipitation (stream flow)
More salmon
More downwelling
Higher Zooplankton
Higher/stronger stratification
Higher Primary Production
Higher SST
Higher Nutrients
Higher Salinity
Shallower Thermocline
Higher sardines
Stronger wind stress curl
Higher Zooplankton
Stronger westerlies
Higher Primary Production
Stronger mixing
Higher Nutrients
Faster
Deeper thermocline
Weaker upwelling
Slower California Current
Less salmon
Less Anchovies
Lower precipitation (WA)
Less seabirds
Lower Zooplankton
Higher stratification
Less rockfish
Lower Nutrients
Lower Salinity
More Sardines
Lower Primary Production
Higher SST
Species movement
Higher precipitation (CA)
Faster
TZCF
Shallower thermocline
Higher Productivity
Weaker CUC
NEC
Less Yellowfin Tuna
Less transport
More Yellowfin Tuna
NECC
SEC
Deep Thermocline
Weaker Upwelling
Shallow Thermocline
Lower Production
Lower Nutrients and CO_2
Less transport
Coast of Peru has the same conditions as the California coast

El Viejo

The North American Carbon Program (NACP)

The Program

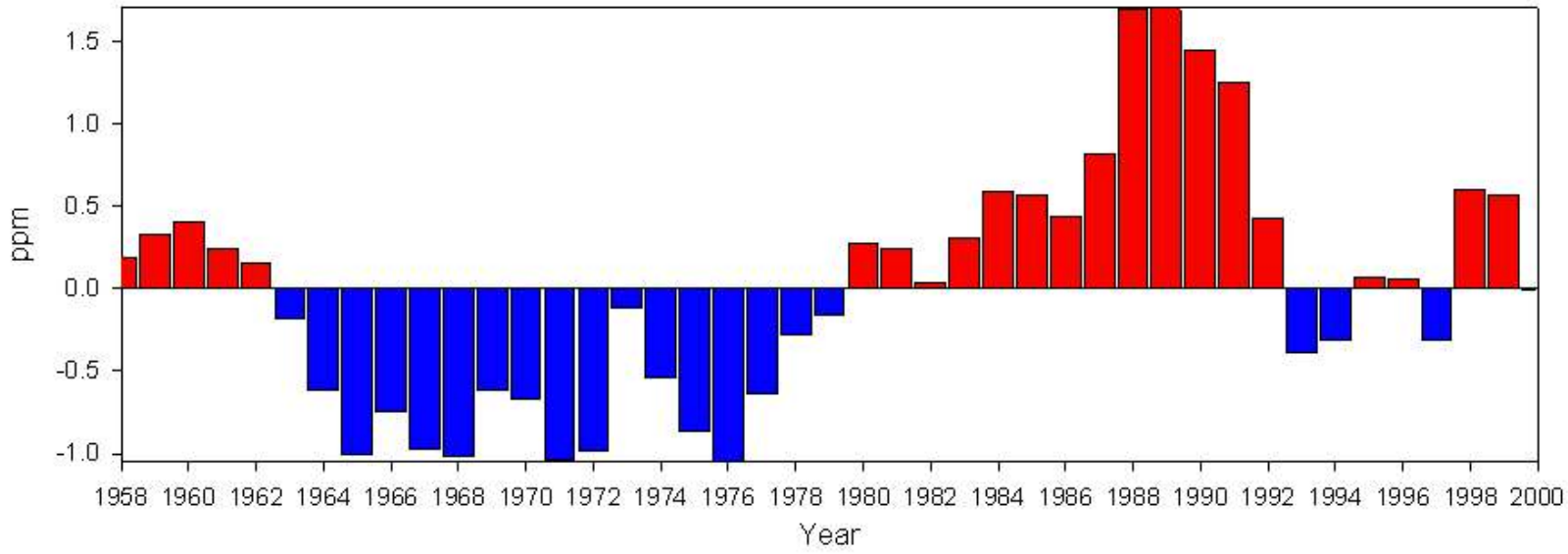
The NACP presents a phased implementation of new research, long-term measurements, and operational observations and analysis in a closely coordinated, integrated Program. There are major initiatives in three key areas:

- **Atmospheric measurements;**
- **Observations, process studies, and modeling of land ecosystems (plans and soils) and adjacent ocean basins;**
- **Models that integrate atmospheric, land, and ocean data, leading to a fundamentally new system for fusion of models and data to diagnose exchange fluxes between the earth's surface and the atmosphere. The set of integrated tools and methods will provide the foundation for improved U.S. inventories of, and trends in, CO_2 and CH_4 sources and sinks.**

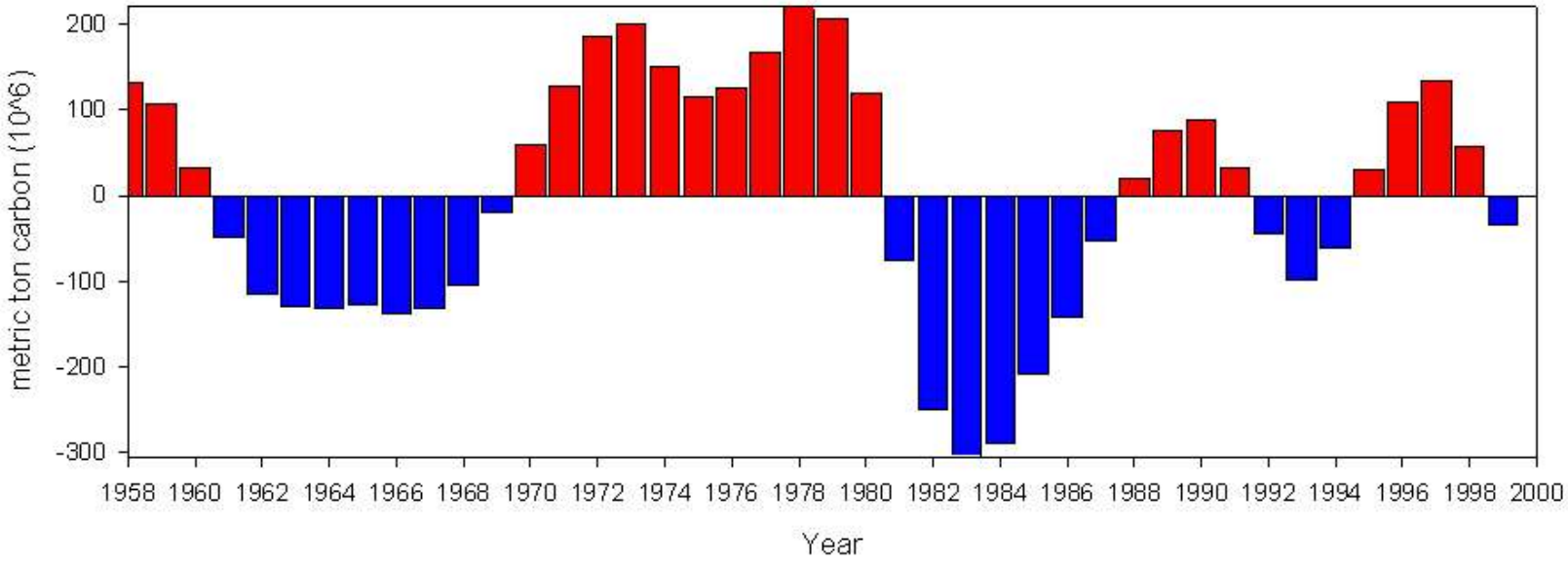
Management

This program, due to its integrated, collaborative nature, requires extraordinary management arrangements. The various elements of the program will be implemented be several different agencies which should obtain scientific guidance from a unified science advisory committee to ensure that elements of the program are working together as necessary. There is already remarkable coordination between agencies, at the level of scientific research programs, through the Carbon Cycle Interagency Working Group (CCIWG, see above for membership). The CCIWG commissioned the current plan to help implement a major element recommended in the Carbon Cycle Science Plan. The NACP will require a comparable degree of integration and coordination at the policy-making levels of the responsible Federal Agencies.

Mauna Loa



Total CO2 Emissions



Major Program Elements of the NACP

1. Atmospheric measurements and field programs

1a) Long Term Measurements of the Atmospheric Carbon Budget

1b) Intensive field programs

2. Inventories and land and ocean surface processes and fluxes

2a. Terrestrial Measurements and Modeling: understanding the terrestrial biosphere.

2b. Marine measurements and modeling: understanding physical and biological processes in ocean basins adjacent to North America

3. Integrating Models and Model-Data Assimilation

Highest Priority Enabling Developments for Immediate Action

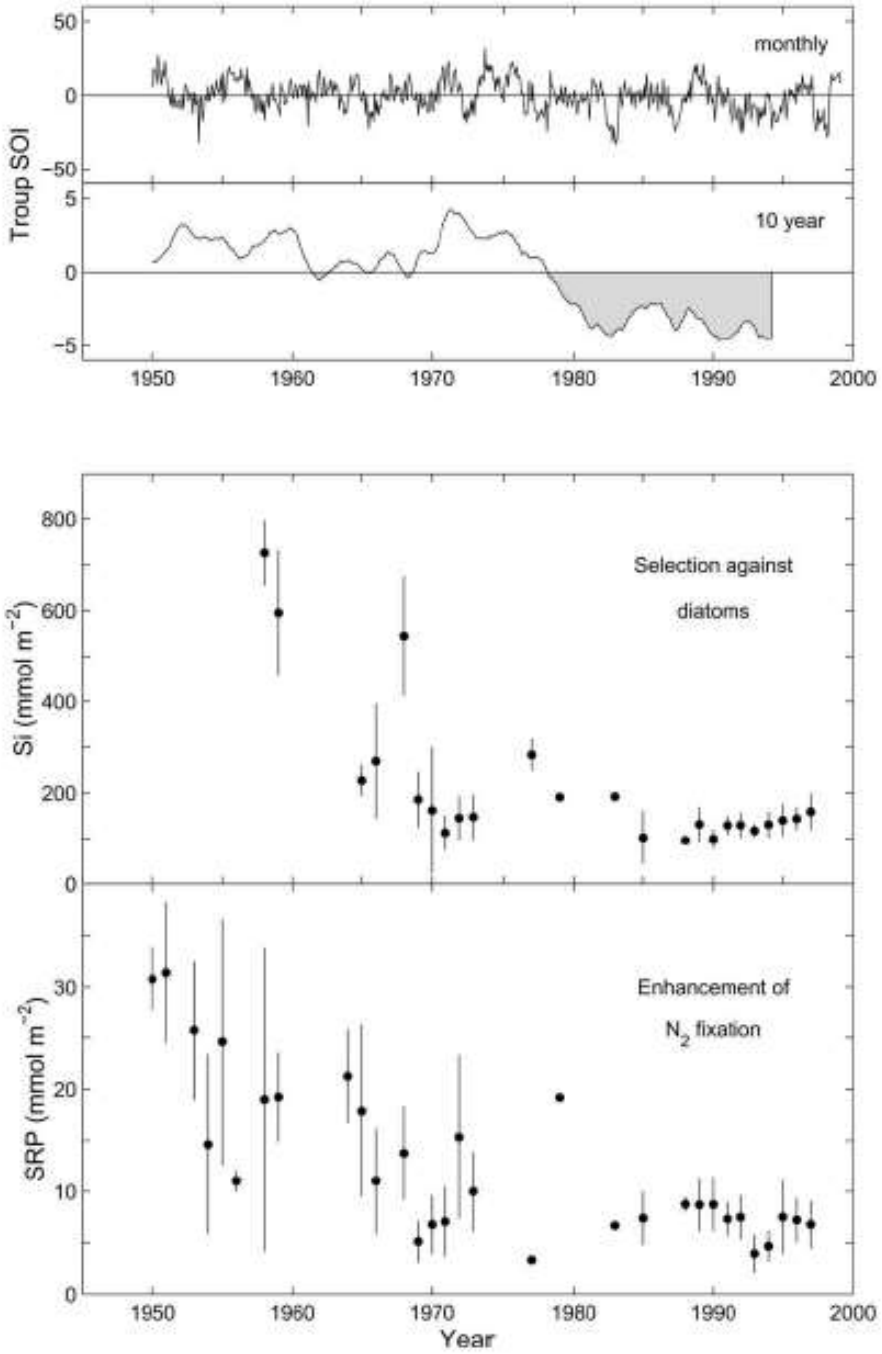
1. Develop *in situ* sensors and sampling protocols
2. Model studies of network design and model-data fusion
3. Optimize inventories (FIA and NRI) for carbon accounting.
4. Strengthen current observation networks.
5. Improved data bases for fossil fuel use and land use/land cover.
6. Remote sensing technology development

Motivation for the North American Carbon Program

Global CO_2 data indicate significant uptake of CO_2 by the terrestrial biosphere in North America, but the conclusion is controversial because the data are seriously inadequate. There is a strong demand to determine accurately the magnitude of current uptake and the reasons it, for international negotiations, to enable carbon trading, and to guide wise policy decisions.

The NACP will provide scientific and technical tools to diagnose past and current sources and sinks of greenhouse gases, and to predict future contributions from North America. Knowledge gained in the NACP will help design global measurement strategies and will inform decisions on policies to reduce net emissions of CO_2 and CH_4 from North America, or to enhance sequestration of carbon through land management or by technical means.

The Program is carefully designed to advance science for other critical problems: **(1)** large-scale sources and long-range transport of air pollution; **(2)** vegetation changes and ecosystem health, productivity, and vulnerability to fire and drought for agriculture, forests, and wild lands; and **(3)** weather forecasts and climate models.


Troup SOI
monthly
10 year
50
0
−50
5
0
−5
1950
1960
1970
1980
1990
2000
Si (mmol m^{-2})
Selection against
diatoms
800
600
400
200
0
SRP (mmol m^{-2})
Enhancement of
N_2 fixation
30
20
10
0
Year